CMOS COMPRESSED IMAGING BY RANDOM CONVOLUTION

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OBJECTIVES:

∗ CMOS Imager with Compressed Sensing coding

∗ Simple (light) and fast compressed encoding + “fast” decoding

⇒ Random Convolutions [1] performed on the focal plane

∗ Reduced power consumption (*wrt* pixel scanning)

∗ Almost “Isometric” compression (since *random projection*)

I. COMPRESSED SENSING (briefly) [2]

Image: $x = \Psi\alpha \in \mathbb{R}^N$

Sparsity basis: $\Psi \in \mathbb{R}^{N\times N}$ (e.g. Canonical, Wavelet, DCT, ...)

A priori: $\alpha \in \mathbb{R}^N$ is K-sparse (or *compressible*),
or x must have a “sparse” gradient.

Sensing model: $y = \Phi x = \Phi\Psi\alpha \in \mathbb{R}^m,\ m < N$

$\Phi \in \mathbb{R}^{m\times N}$ is the *Sensing* matrix

Reconstruction:

∗ Not linear (on high CPU device)

∗ Requirements: $\Theta = \Phi\Psi$ must be a **RIP** matrix !

∗ If Φ is a Gaussian Random matrix,

$$m \geqslant O(K \log N/K)$$

∗ If $\Phi = \underbrace{\mathcal{S}}_{\text{Random selection}} \mathcal{F}^T H \underbrace{\mathcal{F}}_{\text{Fourier}} = \mathcal{S} \circ (h * \cdot)$, with $H = \mathcal{F}h$

$$m \geqslant O(K \log N/K) \quad \text{and} \quad m \geqslant O(\log^3 N/\delta)$$

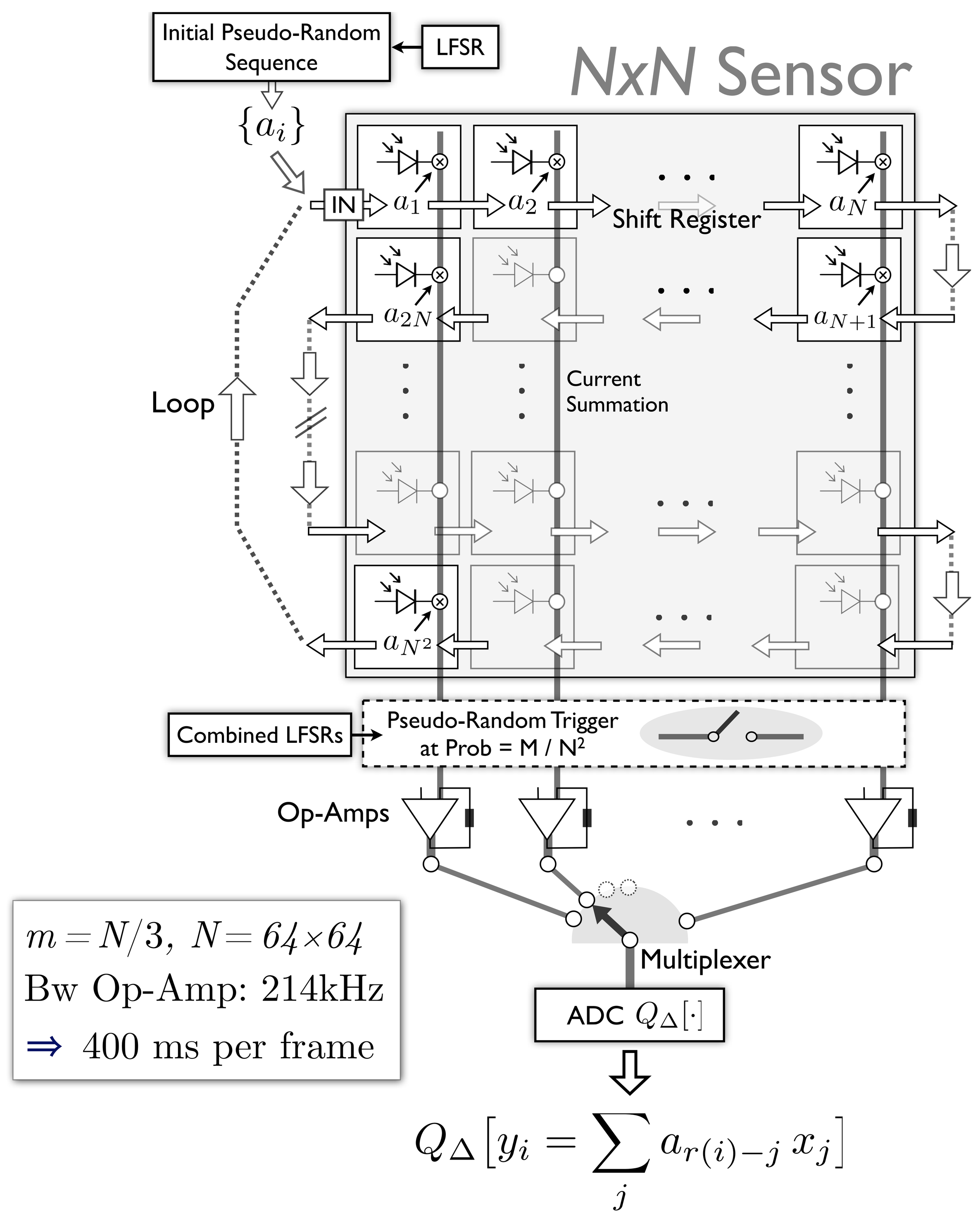
⇒ *Random Convolution* [1] ⇒ *but fast coding and faster decoding!*

∗ Decoding: *Basis Pursuit DeNoise* (BPDN) or *TV* variant

$$\arg\min_x\ \Sigma(x,\alpha) \ \text{ s.t. } \ \|\Theta\alpha - y\|_2 \leqslant \epsilon$$

with $\Sigma(x,\alpha) = \|\alpha\|_1$ or $\|x\|_{TV}$

II. DESCRIPTION OF THE IMAGER



∗ Compressed Sensing Coding ⇔ Analog Signal Processing

∗ Idea: 1-bit *Shift Register* in the focal plane contains h

∗ Convolution by h obtained by:

∗ current flipping by 1-bit SR $h_i = \pm 1$ (pseudorandom)

∗ shifting SR between measurement ⇔ pushing bits (box [IN])

∗ summing currents ⇔ *Kirchoff* law (in wires)

∗ (pseudo) randomness ⇔ convenient use of LFSRs

∗ Current practical choices: (CMOS chip to be manufactured)

∗ 64×64 CMOS Passive Pixel Sensors (PPS, 200µA), 30µm×30µm

∗ 1-bit flip-flop SR, Op-Amp with bandwidth 214kHz

∗ Sums are multiplexed (column by column) to reduce currents

III. PREVIOUS WORKS

∗ One-pixel Camera of Rice University [3]

∗ Digital Micromirror Device (random pattern) + 1 photosensor

⇔ Analog random sensing in the optical domain

∗ But extra non-linearities due to DMD, optics, ...

∗ CMOS Analog Imager of Georgia Tech [4]

∗ General implementation (Transform coding, noiselet, DCT ...)

∗ Larger architecture and larger onboard memory

III. CODING/DECODING SIMULATION

∗ 256×256 images + thermal noise + 11-bits quantization of y

∗ $y = \Phi x + n,\ n_i \sim_{\text{iid}} N(0,\sigma),\ \sigma^2 = \sigma^2_{\text{th}} + \sigma^2_{\text{ADC}} + \frac{\Delta^2}{12}$ $(\sigma \simeq \|y\|_\infty/100)$

∗ Reconstruction with BPDN-TV, $\epsilon \simeq \sigma\sqrt{m}$ (by *proximal* methods)

Original Image (Lausanne)

$m = N/3$, PSNR = 27.3 dB

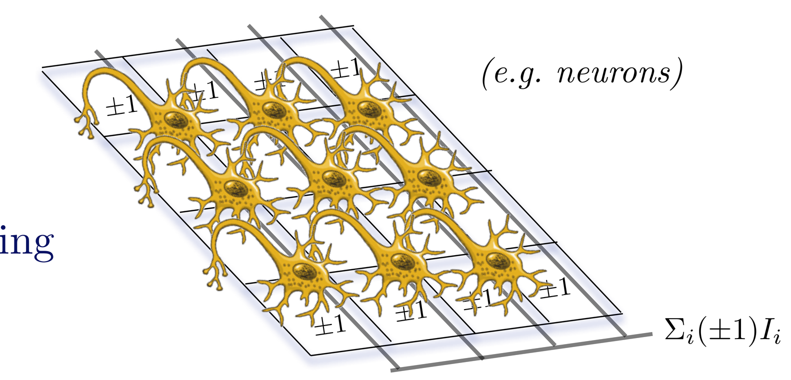
IV. POSSIBLE EXTENSIONS

∗ Using Basis Pursuit *DeQuantizers* BPDQ [5] for $Q_\Delta[\cdot]$

$$\arg\min_x\ \Sigma(x,\alpha) \ \text{ s.t. } \ \|\Theta\alpha - y\|_p \leqslant \epsilon, \quad \text{with } p \geq 2$$

∗ Adapting the sensor to a grid of biocompatible electrodes [6]

⇒ totally equivalent compressed coding



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